BT-1038.09

Tethered Hot Air Balloons

Raven Industries, Inc.

James Winker

Oct 1967

IX. Tethered Hot Air Balloons

James Winker
Raven Industries, Inc.
Sioux Falls, South Dakota

Abstract

In spite of the many advantages of conventional captive balloons which make them useful vehicles, there are a few drawbacks which do limit their application, particularly in short term operations. These include cost of the lifting gas, time and care required for inflation, and the problem of protecting the inflated balloon between uses. The hot air tethered balloon goes far toward solving these problems and it makes practical some applications for which tethered balloons might not otherwise be considered. Presented here are some of the factors which should be considered in a hot air tethered operation and some of the programs which have utilized hot air balloons.

1. INTRODUCTION

Much work has been done in the past few years to expand and develop the capabilities and uses of tethered balloons. Most of this effort has gone into helium balloons, and rightfully so, since this is the buoyancy medium suitable to the widest variety of captive balloon uses. There are, however, a growing number of applications for tethered balloons where the use of helium (or other light gases) entails procurement or handling problems which relegate those applications to impracticality. This leaves a convenient niche for a balloon which can obtain its buoyancy from the surrounding atmosphere. The hot air tethered balloon is hardly a universal tool, but where convenience and low operating cost are important, it offers some very distinct advantages.

2. SYSTEM DESCRIPTION

2.1 Design

Just as with helium balloons, the hot air tethered balloon may come in a number of shapes. Presently the only operating systems are natural shaped balloons, simply because this tool has been adapted from a standard free-flight vehicle design. Three sizes of such balloons are in general use; 40, 50, and 60 ft in diameter.

The balloons are constructed of a nylon fabric which has excellent resistance to the combustion product within the balloon. This is a noncoated material which is woven tightly enough to limit gas leakage to about 1 cfm/sq ft at the normal pressure differentials. This leakage is less than the volume of the exhaust products generated during normal operation. The balloon is built to conform with certification requirements prepared by the FAA which include safety factors up to 5 for the structural elements.

The balloon material has proved to be remarkably durable. Users report operating a balloon for over 100 flights totaling several hundred hours of flying time. The limitation in envelope life is as much determined by normal wear and tear as it is on basic degradation of the material. Somewhat arbitrarily we have established a life limit at the point where fabric strength has diminished to 50 percent of the original tensile and tear values. This still exceeds the safety factor requirements for the relevant parts of the structure.

A general view of the gondola and lower part of the envelope for an S-50 balloon system is shown in Figure 1. The gondola provides space for fuel tanks, flight instruments, a pilot and passenger, and experimental equipment if required. It also provides a mounting for the propane burner which supplies the necessary heat for buoyancy. The burner has a peak output of 2.4 million Btu/hr which in thermal energy is equivalent to over 900 hp. The larger balloons are generally "twin engined" to provide a wide clearance area around the flame. The gondola is suspended from the envelope by steel cables and the entire harness assembly is surrounded by a fabric skirt. The skirt protects the flame from winds which could deflect the heat and cause damage to the envelope. Vents at the top of the skirt allow the exhaust products to bleed out at that level rather than filling the entire skirt and possibly choking the flame.

Buoyancy is controlled by adjusting fuel flow through a dual path. The normal buoyancy level is set by metering the flow through a needle valve. If a rapid increase in buoyancy is required, a toggle valve is operated which instantly provides maximum fuel flow. Deflation of the balloon envelope is facilitated by a large, replaceable deflation port built into the top of the balloon. When the gondola is on the ground and the flame turned off, this port is peeled open by pulling on a strap which extends down into the gondola.

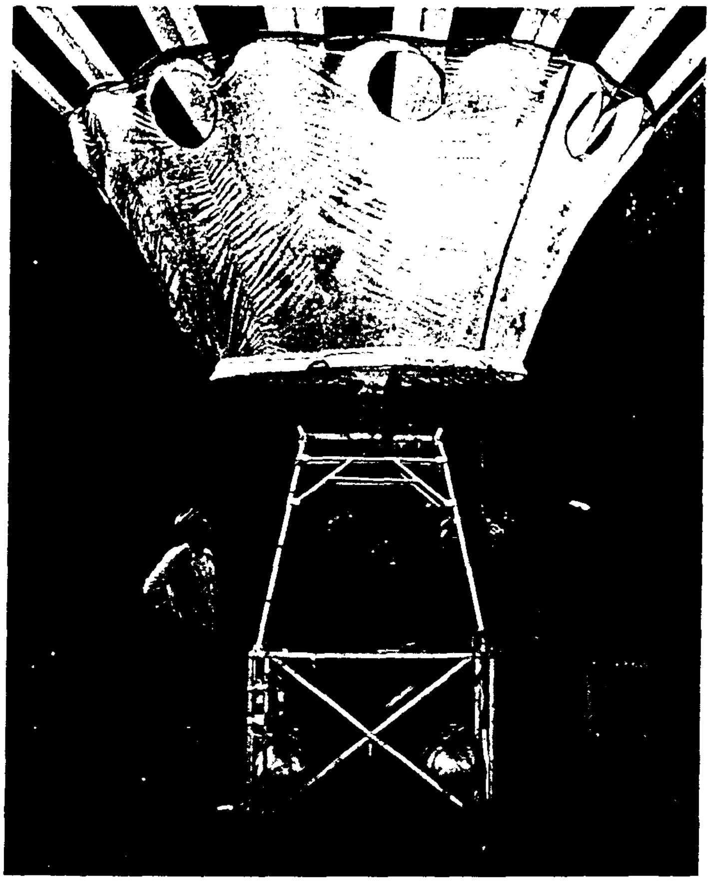


Figure 1. Typical S-50 Configuration

For some applications, it may be a detriment instead of an advantage to carry personnel aboard the balloon during test work. A simple, unmanned gondola is available (Figure 2) which can be automatically and/or remotely operated. In this system the needle valve is again used to provide a sustaining level of heat input and is set for approximately neutral buoyancy. The burner is then modulated between this sustaining level and full output by a solenoid valve which is controlled by a thermostat located in the top of the balloon. Override of the automatic control, and fuel shutoff can be accomplished by radio command or wire link.

The balloon may be tethered at various points on the gondola or even on the envelope itself. The most practical points for tethering seem to be at about waist level or at the burner bar on manned balloons and at the base for unmanned gondolas.

2.2 Performance

The buoyancy of hot air is dependent upon ambient temperature and differential temperature between the inside and outside of the balloon. It is, of course, variable

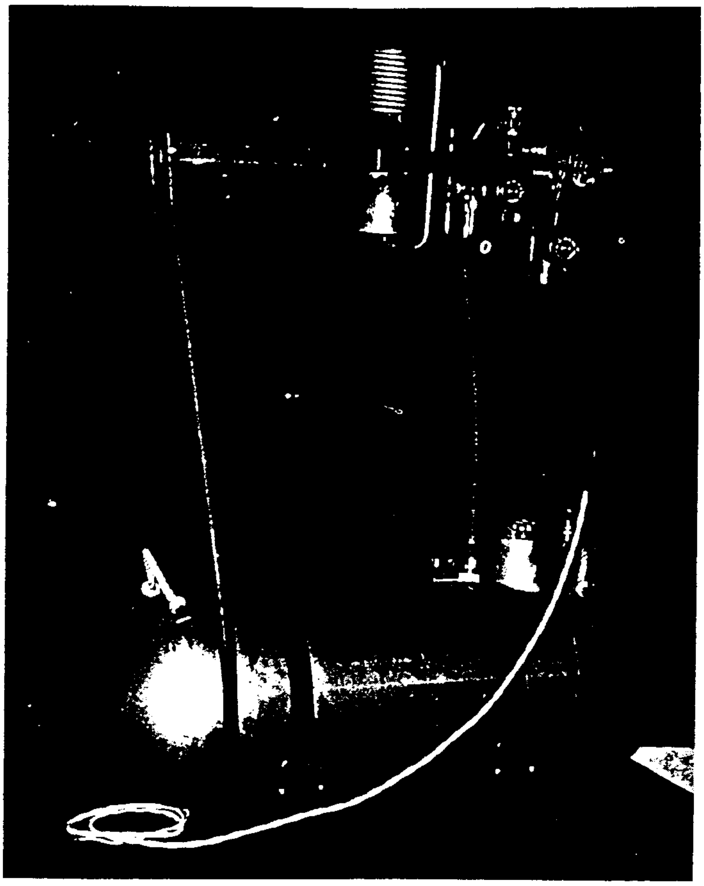


Figure 2. Unmanned Gondola

and in the normal operating range has between 25 and 35 percent of the lift of helium. This requires an envelope dimension of about 50 percent greater than a helium envelope for the same lift.

Figure 3 shows the specific lift of hot air for a range of internal temperatures at sea level standard conditions. Balloon internal temperature is limited to 250°F for sustained operation. A temperature of 300°F is permissible for short term operation and will not unduly shorten the life of the envelope. It is evident that the maximum obtainable lift factor will be less on warm days and greater on cold days because of the variation in allowable temperature differential.

Figure 4 shows the lifting capacity for the three standard balloon sizes at sea level conditions and for a range of ambient temperatures. The "dry weight" shown on the chart is meant to show typical values rather than a definite fixed weight, because there are many options for gondola configuration and fuel tankage which affect this number.

On a standard day (59°F) it may be noted that the S-50 has a gross lift of about 1300 lb. The balloon and fuel might weigh 550 lb, and allowing 250 lb for free lift, a useful payload allowance of 500 lb remains. Comparable numbers for the S-40 and S-60 are about 250 lb and 1100 lb, respectively.

The hot air tethered balloons now in operation all have open base, zero pressure envelopes. This type of balloon has an operating wind limit which is in some degree proportional to the specific lift of the hot air. At some wind velocity the dynamic pressure against the surface of the envelope will overcome the internal pressure produced by buoyancy and cause dimpling in the envelope contour. While this is not truly the limiting condition for tethered operation, it does define a point

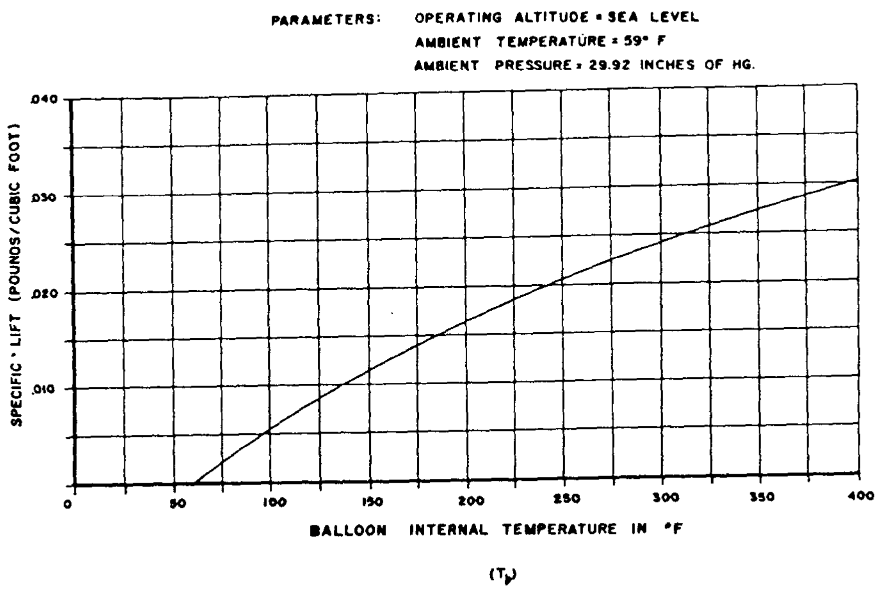


Figure 3. Specific Lift vs Balloon Internal Temperature

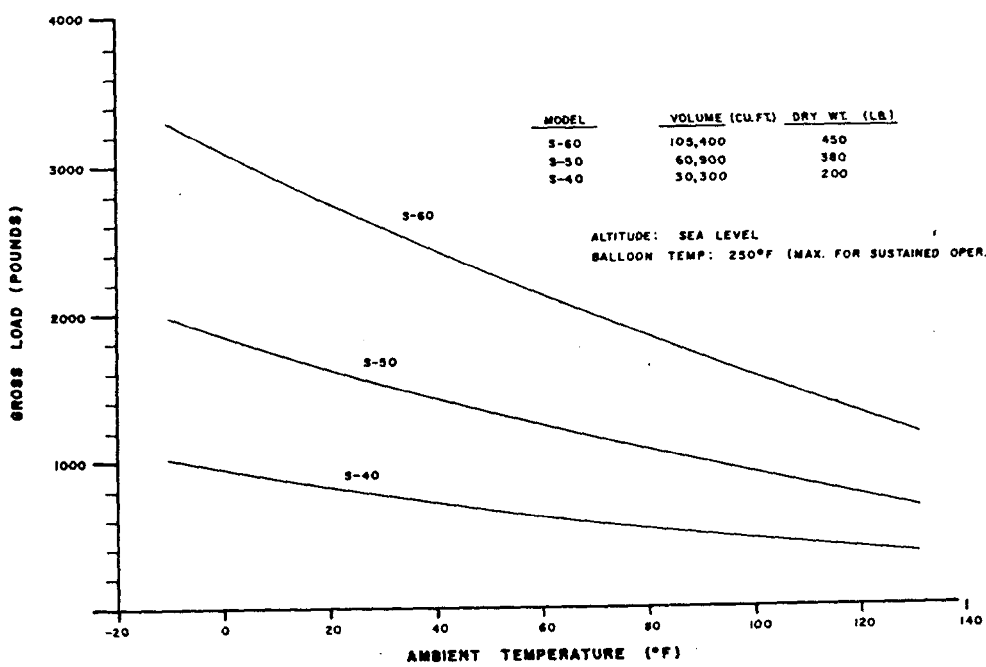


Figure 4. Maximum Authorized Operating Limits for S-40, S-50, S-60

above which instability can occur. Experience indicates that the balance of internal and external pressures at about the 25 percent Gore station determines whether or not the balloon envelope will dimple. Figure 5 compares the internal pressure at this point over a range of temperature differentials against the external dynamic pressure over a range of wind velocities. This shows that under peak temperature conditions, the wind limit to avoid dimpling is about 12 knots.

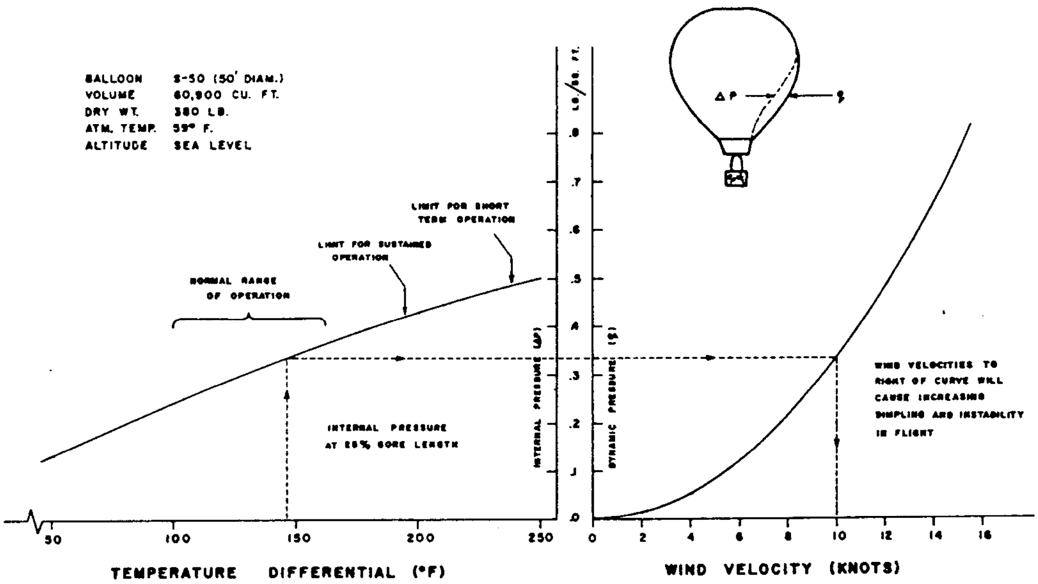
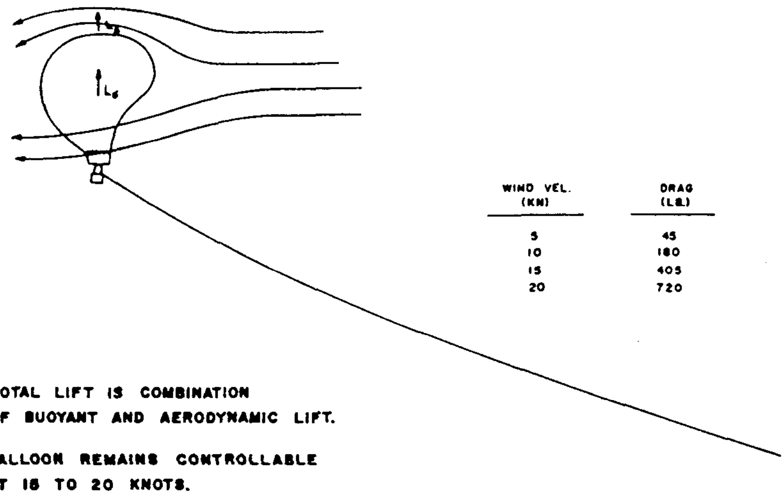


Figure 5. Envelope Dimpling Limits

Flight above the dimpling limit is entirely possible and with an experienced crew may be considered almost routine. The distortion caused by dimpling actually develops a crude airfoil shape in the envelope which adds to the lift of the system. The balloon may be flown in this manner in winds of approximately 18 to 20 knots, though at the upper limit the aerodynamic lift starts to become erratic. Figure 6 is a sketch showing the typical configuration of unpressurized balloons in high winds.

An alternate configuration for high wind operation would be a pressurized natural-shape envelope which is kept full by a blower-burner combination. Some work along this line is now in process. A higher degree of sophistication is also possible in the form of a pressurized aerodynamically shaped envelope. This is entirely feasible and can be developed whenever a customer presents the requirement.



WIND VEL. (KN)	DRAG (LB)
5	45
10	180
15	405
20	720

Figure 6. Action of Unpressurized Balloon in High Wind

3. APPLICATIONS

3.1 General Considerations

The relative merits of light gases and hot air determine which lifting medium is most appropriate for a given application. Light gases, such as hydrogen and helium, must be used for high altitude flight and may be preferable where long, continuous use is intended. Helium will usually have an advantage where high winds must be contended with, and for short term, high frequency uses in situations where a balloon can be stored indoors between uses. Hot air has its greatest advantage for low level operation, where per flight cost is critical, and where convenience of inflation and launching is important. Also, a major advantage is realized when the weight or logistics problems of handling compressed gas tankage limits the use of helium.

It would be very difficult to draw up a list of criteria for comparison between the two lifting media which would unequivocally show which one is more appropriate. A hypothetical case shows some of the factors which must be considered. Assume that it is necessary to lift a 400-lb payload less than 1,000 ft above sea level and have it in this position at frequent but unscheduled intervals over a period of many weeks. Further, the area is somewhat remote and not served by railroad or surfaced highways.

A helium balloon for this job might have a volume of 10,000 cu ft and a purchase price of about $6,000. The hot air balloon should have a volume of about 60,000 cu ft and it too would cost about $6,000. Operating costs for the hot air balloon will be about \$2.00/hr for fuel used while actually in flight. Cost to fill the helium balloon would be \$500 to \$800, depending on the source and shipping distance for the gas. The weight for the balloon, payload and gas tankage would be about 5,000 lb for the helium system and 800 lb for the hot air balloon plus 40 lb of fuel per hour of operation.

To be economically competitive at all, the helium balloon would have to be kept inflated throughout the operation and would have to be capable of surviving any wind which might occur. The hot air balloon can be unpacked, inflated, perform its mission and be repacked and stored until the next use in little more time than it takes actually to perform the experiment. Adverse winds can be avoided, and yet within the wind limitation for the balloon, it is available to perform its service almost at a moment's notice. It is practical to erect it for usage times as short as just a few minutes, and with on-board fuel the balloon can remain in operation for as long as 4 to 6 hours. Greater durations can be attained if necessary by piping fuel from the ground to the balloon.

Inflation requires no elaborate preparations and can be done on open ground in winds up to about 10 knots. The time elapsed from roll out of the envelope to flight-ready status is as little as 5 to 10 min. Deflation and packing up require about the same time.

As can be readily seen, the characteristics of the two classes of lifting media are not directly comparable. Each application for which hot air might be considered must be evaluated individually to determine if hot air is indeed the preferred lifting gas.

3.2 Observation Platforms

Some of the first uses for tethered hot air balloons were simply as carriers for a human observer who needed the convenience of a high vantage point. Figure 7 shows a relatively simple application which in itself has no vital importance but offers evidence of the convenience of operation of the hot air balloon. The large balloon in the foreground is a heavy lift vehicle with a lifting capacity of 15,000 lb. In the first test inflation, a situation developed which made it important to observe visually the region around the top fitting of the balloon. On a spur of the moment basis, the hot air balloon was erected, the observation made, and the balloon returned to the ground all within an hour.

One user has purchased a balloon for a biological study program. His intent is to tether the balloon to a boat and drift offside over a herd of whales. The observer manning the balloon can then easily watch and study the life habits of these large mammals without intruding upon them in their natural environment. The United States Bureau of Fisheries has done some similar experimentation to see if schools of tuna fish can be detected from such a balloon. If this technique proves to be useful, it might very well be used commercially by tuna fishing fleets.

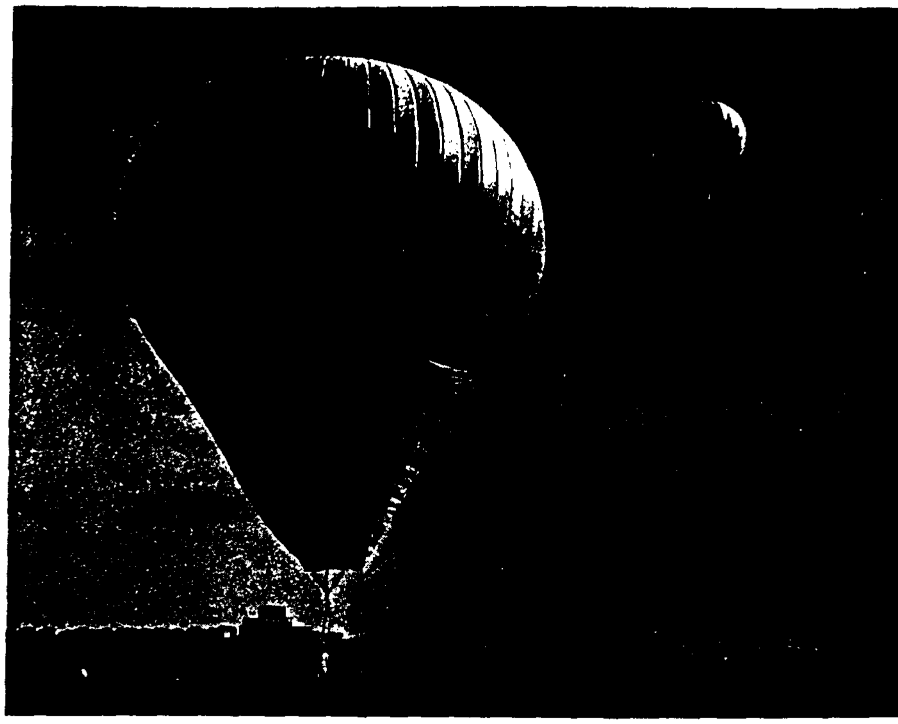


Figure 7. Hot Air Balloon as an Observation Platform

An S-40 balloon was purchased by Philippe Cousteau for use in conjunction with the research vessel Calypso. The research crew of the ship is involved in both underwater and surface observations and the balloon will provide assistance in a number of ways. It again will be used to observe marine life in the immediate region below the surface of the ocean. It will also be used in studies of the interaction between the sea and the atmosphere. In underwater work, it is typical for scuba divers to surface a considerable distance from the ship at the completion of their duties. Locating and recovering them is often a protracted exercise and it is expected that a spotter riding the balloon can speed this operation and cut the waiting time for the divers.

3.3 Drop Vehicles

Tethered hot air balloons have been used as platforms from which to drop test bodies. The Kaman Aircraft Corporation of Bloomington, Connecticut has used an unmanned balloon to lift and drop their Rotochute, which is a rigid-body aerodynamic decelerator. The balloon was anchored by a tripod tether arrangement and the test device was supported at the apex of the tripod. The assembly was lifted to about 3, 000 ft where the body was dropped.

The Equipment Development Center of the Forestry Department has purchased a balloon for a variety of uses, one of which is to serve as a jump platform for training parachute jumpers.

3.4 Test Platforms

Two military organizations have made extensive use of tethered balloons as test platforms. The Naval Weapons Center at China Lake, California has three balloons which they use for photographic and instrumentation platforms. These are used for testing small ordnance devices or complex electronics systems. These tests must be run in a near simulation of operational conditions which means that they must not be in the proximity of a large carrier vehicle such as an aircraft. At the same time, personal attention is required to monitor the performance of the devices and to make manual adjustments during the test period. It is claimed that use of the balloon cut six months off the development time of a major missile system. One of the NWC balloons is shown in Figure 8.

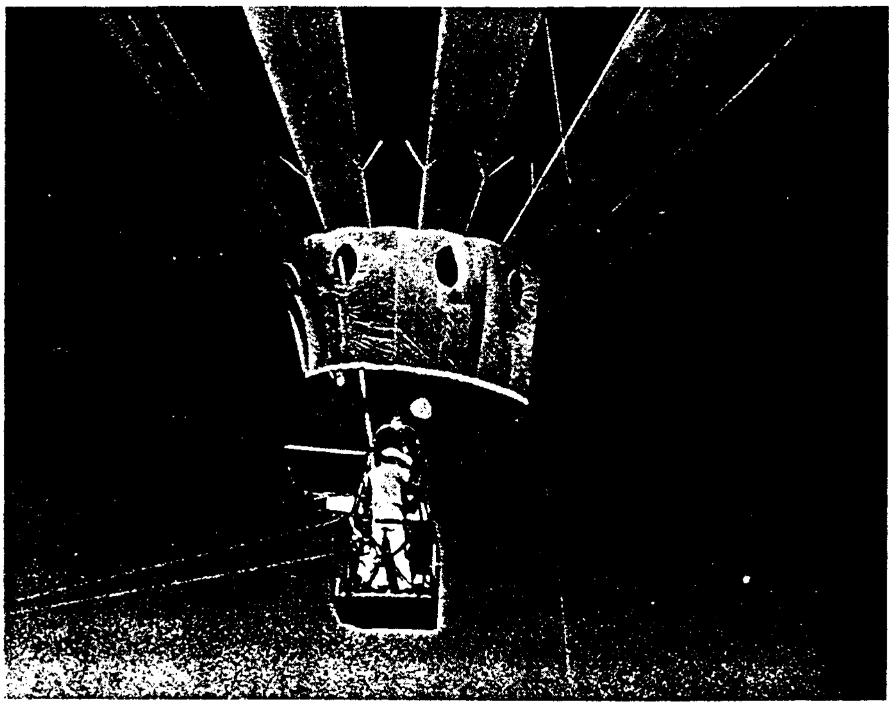


Figure 8. Naval Weapons Center Balloon

The Air Force Armament Laboratory at Eglin AFB uses a model S-60 balloon in much the same manner as the NWC balloons. They use it to test ordnance fuses and laser devices where the experiment requires that a ground objective be approached from different levels and elevations. They feel that the hot air balloon fills a gap between the capabilities of helicopters and conventional aircraft.

Another, quite different use will be attempted soon in a weather modification experiment. Mr. Charles B. Moore, of the New Mexico Institute of Mining and Technology, will use a hot air balloon to lift a large diameter, lightweight tube about 1,000 ft into the atmosphere from the top of a 10,000 ft mountain. A blower at the base of the tube will induce a flow up through the tube and out its upper extremity. Before entering the tube, the air will pass through a particle generator, which will load the air with particles having an average diameter of 0.1μ, in a concentration of 10^8 particles/cm^3. An electrostatic precipitator will apply a charge to each particle. The effect of pushing the cloud of charged particles up into the atmosphere will be something akin to a Van de Graaff generator and it is expected that this artificial electrification process will have a pronounced influence on precipitation.

4. CONCLUSIONS

The tethered hot air balloon is a research tool which provides capabilities not fully available from any other type of airborne device. In comparison with heavier-than-air craft, it and helium balloons have similar advantages in that they offer stable, relatively fixed, inexpensive test platforms. In certain applications the hot air balloon has further advantages over helium balloons in that it offers a much simplified logistics effort, frequently at lower cost, and a much higher degree of convenience in operation.

Flight experience with hot air tethered balloons includes thousands of hours of operation with no known accidents. Performance levels which have been achieved and which should be attainable are as follows:

	Performance Achieved	Probably Attainable
Loads	up to 2,000 lb	at least 10,000 lb
Wind limit	15 - 20 knots	25 - 35 knots
Duration	6 hr	unlimited with ground fuel
Maximum altitude	3,000 ft	10,000 ft reasonable; possibly 25,000 ft